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Substitution of Canola Meal for Soybean Meal in Diets for Channel Catfish *Ictalurus punctatus*

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Abstract

Canola meal was used in channel catfish *Ictalurus punctatus* diets at levels of 0, 15.4, 30.8, 46.2 and 61.6%, by progressively replacing (on an equal nitrogen basis) 0, 25, 50, 75, or 100% of solvent-extracted soybean meal in the control diet. The feeds were formulated to contain approximately 29% crude protein and 2,650 kcal of digestible energy/kg on an air-dry basis. Each diet was fed to juvenile channel catfish to satiation twice daily for 10 wk. Fish fed the diets containing the two lowest levels of canola meal (15.4 and 30.8%) had similar weight gains, feed intakes, feed utilization efficiencies, and percent survivals relative to the group fed the control diet. Weight gains and feed intakes declined significantly as the dietary levels of canola meal were increased to 46.2% or higher, probably because of reductions in diet palatability and some impairment of feed utilization due to the presence of increased levels of antinutritional factors, particularly glucosinolates. Whole body percentages for moisture and crude protein were unaffected by the dietary treatments. Body ash contents, however, were lowest for fish fed the control diets but were essentially the same for fish fed the other diets. Fish fed the diet containing 30.8% canola meal had lowest body fat content but this effect may not have been diet related. Values for red blood cell concentration, hemoglobin, mean corpuscular volume, mean corpuscular hemoglobin and mean corpuscular hemoglobin concentration were not affected by dietary canola meal level, but hematocrit was higher (although not always significant) for fish fed the control diet. The results of this study suggest that canola meal can comprise about 31% of the diet of channel catfish by replacing half of the amount of soybean meal used in the control diet without adversely affecting growth or any other aspect of performance.

Soybean meal is the most abundant source of plant protein and it has one of the best amino acid profiles of all protein-rich plant feedstuffs for meeting the essential amino acid requirements of fish (NRC 1993). Considerable research has been done to assess the potential for using soybean meal as a substitute for fish meal in diets for channel catfish *Ictalurus punctatus* (Lovell et al. 1974; Andrews and Page 1974; Leibowith 1981; Murai et al. 1982; Murray 1982; Wilson and Poe 1985; Moshen 1988; Robinson and Li 1993, 1994a, 1994b). Most studies conducted with small channel catfish in aquaria have shown that total replacement of fish meal by soybean meal results in reduced growth and feed efficiency. Likely, the effects have occurred because of the presence of antinutritional factors and indigestible oligosaccharides in soybean meal. Robinson and Li (1994b) reported that soybean meal is sufficient in all the indispensable amino acids required by channel catfish. Leibowith (1981) reported that soybean meal could replace fish meal in feeds for channel catfish raised at low density in earthen ponds. More recently, Robinson and Li (1993) demonstrated that soybean meal could be used to replace fish meal in feeds for grow-out catfish raised at high density in ponds and fed to satiation. Currently, soybean meal is still the major protein source used in channel catfish feeds, and often this protein source constitutes up to 50% of the diet by weight (Robinson 1991).

Canola refers to new varieties of rapeseed specifically bred to contain much lower levels of deleterious components such as erucic acid and glucosinolates (Higgs et al. 1983). In 1993, the global amount of protein from rapeseed/canola was higher than that of other oilseed meals, except soybeans. Moreover, it is noteworthy that the inherent quality of protein present in rapeseed/canola meals has been found to be similar to that of soybean meal. Also, the cost of canola meal is generally less than that of soybean meal on a per unit protein basis (Higgs et al. 1996). Hardy and Sullivan (1983), for instance, reported that replacement of soybean meal with canola meal in trout diets reduced feed costs by about $19 per metric ton.

Canola meal has been used primarily as a protein supplement for livestock and poultry, but its use in fish feeds has been limited due probably to the presence of high fiber and other indigestible carbohydrates, phenolic compounds such as tannin, sinapine, phytic acid, and glucosinolates (Higgs et al. 1979, 1982, 1995; McCurdy and March 1992). Early research showed that rapeseed meal can comprise at least 28% of the diet for common carp *Cyprinus carpio* (Dabrowski and Kozlowska 1981) and 42% of the diet of tilapia *Sarotherodon mossambicus* (Jackson et al. 1982) without adversely affecting their performance. Davies et al. (1990), however, reported that rapeseed meal at levels higher than 15% of the diet as replacement of soybean meal resulted in poor growth and feed utilization of tilapia *Oreochromis mossambicus*. The acceptable levels of rapeseed/canola meal in the diets of salmonids have been reported to range from 10% to 23% depending on the species and age of the fish, and the glucosinolate content of the meal (Yurkowski et al. 1978; Higgs et al. 1979, 1982, 1983, 1995, 1996; Hardy and Sullivan 1983; Abdou Dade et al. 1990). The situation in channel catfish is presently unclear. Li and Robinson (1994) reported that canola meal can comprise 25% of the diet as replacement of soybean meal without detrimental effects. However, no study has assessed the performance of channel catfish fed diets in which canola meal has been progressively substituted for soybean meal.

Thus, this study was conducted to compare the growth performance, feed utilization, body composition and hematological parameters of channel catfish fed isonitrogenous and isocaloric diets containing progressively higher levels of canola meal through removal of soybean meal.

Materials and Methods

Experimental Diets

Five practical-type diets were prepared to contain 0, 15.4, 30.8, 46.2 and 61.6% commercial canola meal (ADM-Agri Industries Lmt., Winsor, Ontario, Canada) through replacements, on an isonitrogenous basis, 0, 25, 50, 75 and 100%, respectively, of the solvent-extracted soybean meal in the control diet (Table 1). All diets were formulated to contain approximately 29% crude protein and 2,650 kcal of digestible energy/kg (air-dry basis) based on the feedstuff values reported by NRC (1993). The dietary lipid level was maintained constant by the addition of cod liver oil and canola oil. Corn meal, corn starch, and celufil were used to equalize the dietary levels of nitrogen-free extract and crude fiber. Proximate composition of the experimental diets determined by analysis (AOAC 1990) are presented in Table 2.

Experimental Fish and Feeding

Marion-strain channel catfish from a single spawn that had been maintained at the USDA Fish Diseases and Parasites Research Laboratory and fed a commercial diet to an average weight of 7.60 ± 0.03 g were randomly stocked into 15 110-L aquaria at a density of 60 fish per aquarium. Aquaria were supplied with flow-through (0.6–1.0 L/min) dechlorinated tap-water maintained at 25–27 C. Water was contin-

TABLE 1. *Percentage composition of experimental diets (air-dry basis).*

Ingredient	Percent in diet 1	2	3	4	5
Menhaden fish meal	8.0	8.0	8.0	8.0	8.0
Soybean meal (44% protein)	45.0	33.7	22.5	11.3	—
Canola meal	—	15.4	30.8	46.2	61.6
Corn meal	19.0	15.3	11.5	7.8	4.1
Wheat middlings	15.0	15.0	15.0	15.0	15.0
Cod liver oil	2.0	2.0	2.0	2.0	2.0
Canola oil	0.8	0.6	0.4	0.2	—
Corn starch	—	1.1	2.2	3.2	4.3
Dicalcium phosphate	1.0	1.0	1.0	1.0	1.0
Trace mineral mix[a]	0.5	0.5	0.5	0.5	0.5
Vitamin mix[b]	0.5	0.5	0.5	0.5	0.5
Carboxymethyl cellulose	3.0	3.0	3.0	3.0	3.0
Celufil	5.2	3.9	2.6	1.3	—
Percent soybean meal replaced by canola meal	0	25	50	75	100

[a] Trace mineral mix provided the following minerals (mg/kg diet): zinc (as $ZnSO_4 \cdot 7H_2O$), 150; iron (as $FeSO_4 \cdot 7H_2O$), 40; manganese ($MnSO_4 \cdot H_2O$), 25; copper (as $CuCl_2$), 3; iodine (as KI), 5; cobalt (as $CoCl_2 \cdot 6H_2O$), 0.05; selenium (as Na_2SeO_3), 0.09.

[b] Vitamin mixture provided the following amounts (mg/kg diet unless otherwise stated): vitamin A, 4,000 IU; vitamin D_3, 2,000 IU; vitamin K, 10; vitamin E, 50; thiamin hydrochloride, 10; riboflavin hydrochloride, 12; pyridoxine, 10; pantothenic acid, 32; nicotinic acid, 80; folic acid, 2; biotin, 0.2; vitamin B_{12}, 0.01; choline chloride, 400; L-ascorbic acid-2-polyphosphate (15% vitamin C activity); 400, celufil, 3,823.8.

uously aerated and the photoperiod was maintained on a 12-h light: 12-h dark schedule.

Each of the five experimental diets was randomly assigned to triplicate groups of fish and all groups were fed their respective diet to satiation twice daily for 10 wk. During each feeding, feed was offered by hand until satiation was reached. Daily records of feed consumption and mortality were maintained for each group. Water flow rates were checked and adjusted twice daily to insure proper water exchange rate. All aquaria were cleaned once weekly by scrubbing and siphoning accumulated wastes. On cleaning days, the fish were fed only once in the afternoon. Fish in each aquarium were counted and weighed collectively at biweekly intervals. When fish were removed for weighing, the aquaria were cleaned thoroughly and drained. The fish were not fed on sampling days.

TABLE 2. *Proximate composition of experimental diets (air-dry weight basis).*

Diet number	Proximate constituent (%) Moisture	Crude fat	Crude protein	Crude fiber	Ash
1	9.24	4.71	29.80	6.10	6.66
2	9.42	4.78	29.80	6.12	6.75
3	9.18	4.26	29.41	7.10	7.13
4	11.49	4.46	28.78	7.36	7.06
5	9.98	4.40	28.61	8.27	7.49

Body Composition

Twenty fish were collected at the start of the experiment and stored at −20 C for determination of whole body proximate composition. At the end of the experiment, five fish from each aquarium were randomly collected and stored frozen at −20 C for subsequent chemical analyses. Standard methods (AOAC 1990) were used to determine the initial and final whole body proximate composition.

Hematological Assay

At the end of the feeding study, five fish from each replicate were randomly chosen

TABLE 3. *Mean weight gain, percent survival, dry matter feed intake, and feed conversion for channel catfish fed diets containing various levels of canola meal for 10 wk. Values represent mean of* N = *3 determinations/treatment. Means (±SE) in the same column having the same superscript are not significantly different* (P > *0.05).*

Diet number	Weight gain (g)	Survival (%)	Dry matter feed intake (g/fish)	Feed conversion ratio[1]	Apparent protein utilization[2] (%)
1	34.40 ± 1.96^{a}	96.66 ± 1.67^{a}	51.67 ± 0.62^{a}	1.53 ± 0.07^{b}	34.60 ± 2.40^{a}
2	31.96 ± 0.58^{ab}	96.66 ± 1.67^{a}	50.50 ± 0.76^{a}	1.64 ± 0.04^{ab}	32.04 ± 0.49^{a}
3	31.23 ± 2.54^{ab}	95.00 ± 0.96^{a}	47.50 ± 2.41^{ab}	1.56 ± 0.05^{ab}	32.75 ± 1.12^{a}
4	29.26 ± 1.28^{bc}	91.55 ± 2.89^{a}	43.19 ± 1.60^{bc}	1.53 ± 0.02^{b}	34.87 ± 0.80^{a}
5	25.37 ± 0.68^{c}	93.33 ± 4.41^{a}	42.19 ± 0.56^{c}	1.68 ± 0.03^{a}	31.43 ± 0.49^{a}

[1] Feed conversion = Dry feed fed (g)/wet weight gain (g).
[2] Apparent protein utilization = Body protein increment (g) × 100/protein consumed (g).

and anesthetized with tricane methanesulfonate (MS-222, Argent Chemical Company, Redmond, Washington, USA) at 125 mg/L. Blood samples were collected from the caudal vein for determination of hematocrit, red blood cell count, and hemoglobin with heparinized syringes (20 units/mL) affixed with 27-gauge needles. Hematocrit was determined by the microhematocrit method described by Brown (1988). Red blood cell count was determined by diluting whole blood and enumeration in a hemacytometer. Hemoglobin was determined by the total hemoglobin kit (Sigma Diagnostics, Sigma Chemical Co., St. Louis, Missouri, USA), which is a standardized procedure of the cyanomethemoglobin method. Hemoglobin values were adjusted by the cyanomethemoglobin correction factor for channel catfish described by Larsen (1964). Mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH) and mean corpuscular hemoglobin concentration (MCHC) were determined using the standard formulae of Brown (1988).

Statistical Analyses

Data were analyzed using the General Linear Model procedure of SAS (SAS Institute, Inc. 1993). Differences among individual treatment means were tested using Duncan's multiple range test. The differences were considered to be significant at a probability level of 0.05.

Results

The average final weight gain, percent survival, feed consumption, feed conversion and apparent protein utilization are given in Table 3. Fish fed the control diet (diet 1) exhibited the highest weight gain, but this was not significantly different from those fed diets 2 and 3 (15.4% and 30.4% canola meal). Fish fed diet 5 (61.6% canola meal) had significantly poorer growth than those fed diets 1, 2 and 3. Weight gain of fish fed diet 4 (46.2% canola meal) was significantly less than that of fish fed diet 1, but was not significantly different from those of fish given the other treatments.

The trend for dry matter feed intakes of fish was similar to that described for weight gains. No significant differences were found among the feed intakes of fish fed diets 1, 2 and 3. Fish fed diet 4 consumed significantly less feed than those fed diets 1 and 2 but the feed intake of these fish did not differ from those of fish fed diets 3 and 5.

The feed conversion values were unaffected by diet treatment except for the diet that contained the highest concentration of canola meal. In this case, the feed conversion was significantly poorer than those of fish fed diets 1 and 4.

The percent survival of fish and conver-

TABLE 4. *Final whole body proximate composition of channel catfish fed diets containing various levels of canola meal. Values represent means of* N = 3 *determinations/treatment. Means (±SE) in the same column having the same superscript are not significantly different* (P > 0.05).

Diet number	Proximate constituent (%)			
	Moisture	Crude protein	Crude fat	Ash
1	70.45 ± 0.58[a]	16.27 ± 0.39[a]	9.08 ± 0.28[ab]	2.70 ± 0.06[b]
2	70.16 ± 0.17[a]	16.05 ± 0.23[a]	9.67 ± 0.32[a]	3.56 ± 0.03[a]
3	70.76 ± 0.37[a]	15.65 ± 0.12[a]	8.41 ± 0.41[b]	3.49 ± 0.13[a]
4	70.23 ± 0.37[a]	16.07 ± 0.20[a]	9.65 ± 0.12[a]	3.49 ± 0.31[a]
5	71.46 ± 0.32[a]	16.91 ± 0.23[a]	8.99 ± 0.56[ab]	3.48 ± 0.04[a]

sion of dietary protein into body protein (apparent protein utilization) were not significantly affected by dietary levels of canola meal.

Final whole body percentages of moisture and crude protein were not affected by dietary treatment (Table 4). Body ash content, however, was significantly reduced in fish fed diet 1 relative to the percentages of ash noted in fish fed diets 2 to 5, which varied over a narrow range. Fish fed diet 3 had the lowest percentage of body fat, and this was significantly lower than those of fish fed diets 2 and 4. There were no significant differences among the body fat content of fish fed diets 1, 2, 4 and 5.

Values for red blood cell count, hemoglobin, mean corpuscular volume, mean corpuscular hemoglobin and mean corpuscular hemoglobin concentration of the fish were not significantly influenced by dietary treatment (Table 5). The mean hematocrit of fish fed diet 1 was, however, significantly higher than the corresponding values found for fish fed diets 2 and 5. The values for the groups of fish fed diets 2 to 5 did not significantly differ.

Discussion

Results of this study suggest that commercial canola meal can comprise 31% of the diet of juvenile channel catfish or about 36% of dietary protein as a substitute for 50% of soybean meal without compromising their growth, survival, feed consumption, feed conversion or apparent protein utilization. These findings agree with those of Li and Robinson (1994) who reported that pond feeds for channel catfish can contain at least 25% canola meal by replacement of soybean meal without detrimental effects. In common carp, Dabrowski and Kozlowska (1981) successfully replaced 50% of dietary fish meal with 28% rapeseed meal. Further, Jackson et al. (1982) obtained good growth of juvenile tilapia *Oreochromis mossambicus* when the diet contained 41.8% rapeseed meal by removal of

TABLE 5. *Mean blood values of channel catfish fed diets containing various levels of canola meal. Values represent means of* N = 9–15 *determinations/treatment. Means (±SE) in the same column having the same superscript are not significantly different* (P > 0.05).

Diet number	Red blood cell (10^6/mm^3)	Hematocrit (%)	Hemoglobin (g/dL)	Mean corpuscular volume (fL)	Mean corpuscular hemoglobin (pg)	Mean corpuscular hemoglobin concentration (%)
1	2.21 ± 0.11[a]	31.47 ± 0.33[a]	6.80 ± 0.52[a]	145.29 ± 1.77[a]	31.27 ± 2.36[a]	23.76 ± 2.64[a]
2	2.00 ± 0.08[a]	28.83 ± 0.09[b]	8.03 ± 0.86[a]	140.98 ± 4.06[a]	41.67 ± 4.40[a]	27.90 ± 4.26[a]
3	2.03 ± 0.03[a]	29.70 ± 0.87[ab]	7.42 ± 1.03[a]	145.70 ± 4.43[a]	40.52 ± 3.10[a]	30.54 ± 2.77[a]
4	2.07 ± 0.04[a]	29.83 ± 0.09[ab]	7.34 ± 0.47[a]	143.27 ± 6.06[a]	34.02 ± 3.23[a]	26.10 ± 1.52[a]
5	2.17 ± 0.04[a]	27.60 ± 1.36[b]	6.50 ± 1.47[a]	135.22 ± 7.56[a]	33.63 ± 4.92[a]	30.78 ± 7.94[a]

50% of the fish meal in the control diet. Alternatively, Davies et al. (1990) suggested an inclusion limit of 15% rapeseed meal in the diet of tilapia fry.

Salmonids appear to tolerate lower dietary levels of canola meal than channel catfish. Moreover, studies on salmonids assessing the merits of using rapeseed/canola meal or various upgraded rapeseed/canola protein products have not always reached similar conclusions. For instance, Yurkowski et al. (1978) and Hardy and Sullivan (1983) reported that 20% rapeseed or canola meal or rapeseed protein concentrate can be included in the diet of rainbow trout *Salmo gairdneri* as replacements for soybean meal on an equal nitrogen basis. By contrast, Hilton and Slinger (1986) reported that canola meal cannot successfully replace soybean meal in commercial diets for young rainbow trout at levels of 13.5% of the diet or greater without sacrificing growth. They suggested that canola meal should not be included in the diets for young rainbow trout. Higgs et al. (1979, 1982, 1983) found, however, that rapeseed/canola meals are good protein supplements for juvenile coho salmon *Oncorhynchus kisutch* and chinook salmon *Oncorhynchus tshawytscha* when they comprise 16–20% of the diet.

Canola meal has a relatively good amino acid profile but is slightly lower in lysine than solvent-extracted soybean meal. However, lysine does not appear to be the limiting amino acid in canola meal for fish. Supplementation of lysine and arginine in a diet containing 35% canola meal as a replacement of 10% fish meal failed to improve the growth response of rainbow trout (Hilton and Slinger 1986). Li and Robinson (1994) reported that, based on lysine and sulfur-containing amino acids concentrations of canola meal and on an assumed amino acid availability of 85%, catfish feeds can be formulated to contain up to 50% canola meal and still contain adequate amounts of essential amino acids. Jackson et al. (1982) suggested that essential amino acids are not limited in diets for tilapia even at 75% rapeseed meal level. Thus, the reduced weight gains of channel catfish fed the diets containing more than 31% canola meal in this study appeared to be mainly related to decreases in diet palatability. Dry feed intakes of the fish declined when the dietary level of canola meal was 46% or higher. Interestingly, feed intake of rainbow trout was also noted to significantly decrease when the diets contained 35% or more of rapeseed protein concentrate (Yurkowski et al. 1978). Some of the antinutritional factors in canola meal such as sinapine, a phenolic compound, are known to impart a bitter taste to animals (McCurdy and March 1992). FinnStim, a mixture consisting of 94% betaine and 3% L-amino acids (Clarke et al. 1994) appears to be effective in improving feed intake of trout fed diets containing canola meal (Prendergast et al. 1994; Higgs et al. 1996) or rapeseed protein concentrate (Teskeredzic et al. 1995). High levels of glucosinolates in the diets containing 46% or more canola meal may also have contributed to the decreased growth rates of the fish in these treatments. Although glucosinolate contents of the experimental diets were not determined and the effects of dietary levels of glucosinolates on the performance of channel catfish is unknown, it has been reported that glucosinolates are a major factor responsible for depression of growth and thyroid function in salmonids, common carp and tilapia fed diets with high levels of rapeseed/canola meal (Yurkowski et al. 1978; Higgs et al. 1979, 1982, 1983; Dabrowski and Kozlowska 1981; Jackson et al. 1982; Hardy and Sullivan 1983; Hilton and Slinger 1986; Leatherland et al. 1987; Leatherland and Hilton 1988; Davies et al. 1990).

The reduced body fat content of fish fed diet 3 may not have been caused by the dietary level of canola meal since percentages of body fat were similar in fish fed diets containing lower (diets 1 and 2) and higher (diets 4 and 5) levels of canola meal. The elevated levels of body ash in fish fed diets containing canola meal (diets 2 to 5) likely can be attributed to the higher levels of ash in these diets (Table 2). Results of previous studies on rainbow trout (Yurkowski at al. 1978), chinook salmon (Higgs et al. 1982) and tilapia (Davies et al. 1990), fed diets containing different levels of rapeseed/canola meal, have not shown any noticeable variations in body levels of moisture, protein, fat, and ash.

Except for hematocrit values, hematological parameters were not affected by dietary levels of canola meal. Channel catfish fed the control diet had higher hematocrit levels (not always significant) than the groups fed the diets containing canola meal. Whether one or more of the antinutritional factors present in canola meal affected erythropoiesis of channel catfish in this study is unknown. Hilton and Slinger (1986), however, reported that there were no significant differences in levels of hemoglobin and hematocrit in rainbow trout after 16 wk of feeding practical diets containing various levels of canola meal.

In conclusion, our results suggest that commercial canola meal can comprise 36% of the protein in diets for juvenile channel catfish (30.8% of the diet on an air-dry weight basis) by replacing an equal amount of protein furnished by soybean meal. Increasing dietary canola meal higher than this level adversely affected weight gain and feed consumption. However, it may be possible to increase the acceptable dietary level of canola meal if diets containing this protein source are concurrently supplemented with a diet palatability enhancer.

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